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Effects of CO_2 Enrichment, Ventilation, and Nutrient Concentration on the Flavor and Vitamin Content of Tomato Fruit[1]

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***Abstract*. The flavor and consumer acceptability of tomatoes (*Lycopersicon esculentum* Mill. cv. Tropic) grown in 4 greenhouses with different CO_2-enrichment-ventilation environments and 2 nutrient concentrations (standard and 1.5 × standard) were tested with sensory panels. Enriching conventional ventilated greenhouses to 1000 μl CO_2/liter had no significant effect on acceptability. Lack of ventilation caused a decrease in acceptability while the higher nutrient concentration significantly improved it. Vitamin A content of 'N-65' and 'Tropic' tomatoes was increased with CO_2 enrichment and lack of ventilation, but nutrient concentration had no effect. None of the treatments consistently affected Vitamin C content.**

CO_2 enrichment of the atmosphere within greenhouses is a recommended horticultural practice in cooler climates like the northeastern United States (3, 13, 18) and northern Europe (4, 6). There have been more than 500 studies of the effects of CO_2 concentration on photosynthesis, marketable yield, market quality, and growth rate of many crops (14), but only a few studies on flavor components (7, 11, 17). There are no reports of sensory panel evaluations of crops grown with CO_2 enrichment. Studies on the effects of CO_2 enrichment on human nutritional value are limited to 2 papers on Vitamin C (2, 11). In this paper we report on the effects of CO_2 enrichment, greenhouse ventilation, and nutrient concentration on the flavor and vitamin content of tomato fruit.

The CO_2 enrichment, greenhouse ventilation, and nutrient treatments were the same as those used with a previous winter (1977–78) crop (10): 1) A "ventilated," ambient CO_2 control greenhouse cooled with a conventional fan-pad cooling system when the greenhouse air temperature rose above 26.5°C. 2) A "ventilated," 1000 μl CO_2/liter greenhouse cooled like the first greenhouse, but enriched to 1000 μl CO_2/liter during the daytime whenever the cooling system was off. 3) An "unventilated," 1000 μl CO_2/liter greenhouse equipped with a cooling system that recirculated the greenhouse air through cooled water. The cooling system came on at 26.5°. Ventilation occurred only if the temperature rose to 29.5°. The greenhouse was enriched to 1000 μl CO_2/liter in the daytime when unventilated. 4) An "unventilated," 1350 μl CO_2/liter greenhouse similar to 3, but enriched to 1350 μl CO_2/liter in the daytime when unventilated. All of the greenhouses were subdivided into 2 growing beds. The 20-plant beds on the east side of each house received standard nutrient concentrations (8) while the 30-plant beds on the west side received 50% more concentrated (high) solutions of all elements. The 4 different ventilation-CO_2 environments of the 4 greenhouses constituted 4 treatments of 1 factor, and the 2 nutrient concentrations within each greenhouse constituted 2 treatments of another factor to give a total of 8 individual treatments.

Sensory panel evaluations. Four sensory panels were conducted, one each on January 13, 20, February 3, and 17, 1978. There were 15 untrained panelists per panel, a total of 60 panelists. 'Tropic' tomatoes from the 1977–78 winter crop (10) were harvested at the mature red stage 2 days before testing and the 15 most uniform were selected from the 18 to 25 available from each of the 8 treatments. Additional tomatoes for comparison purpose were purchased at a local Phoenix supermarket on the day before testing. Half of the market tomatoes were from hydroponic greenhouses and the other half were from Mexican fields. The general requirements of the American Society for Testing and Materials (1) for physical conditions and sampling were followed as closely as possible but individual booths were not available, so tables in a large room were used instead. There were 2 panelists per table, each assigned to an end. Panelists were told not to converse and that the samples were randomized so that sample numbers did not agree between neighbors.

Ten white paper plates per panelist were numbered sequentially, and then whole tomatoes from each of the 8 treatments and the hydroponic greenhouse and the field were assigned in a different random order for each panelist. Quality traits were scored from 100 (a perfect tomato) to 0. Panelists were asked to: 1) score the first sample tomato on color and general appearance; 2) cut the fruit and score for texture; 3) smell and score aroma; and 4) taste and score flavor. They were asked to sip water each time before tasting. After scoring flavor, the panelists were asked to give the tomato a score on overall consumer acceptability with regard to whether or not they would want to buy that particular tomato in a market. After scoring sample 1, they repeated with samples 2, 3, etc. When they had finished scoring the 10 tomatoes individually, the panelists were asked to rank them from best to worst. They were allowed to taste back and forth as much as they wished (sipping water each time). The panelists took about 45 ± 10 min to complete all their scoring.

The mean sensory panel scores for color (or general appearance), texture, aroma, flavor, overall consumer acceptability, and rank are presented in Table 1. Picking date had significant effects on acceptability but not on rank, and there were no significant interactions, so the data were pooled with respect to picking date. A comparison between the scores from the experiment tomatoes with those of the market tomatoes provided an overall perspective on the high quality of the experimental tomatoes. The panelists generally rated the experimental tomatoes about the same as they hydroponic greenhouse tomatoes and considerably better than the imported field tomatoes (acceptability scores of 65 and 39, respectively).

The mean scores of the ambient-ventilated and the 1000 μl CO_2/liter-ventilated treatments were not significantly different for any of the quality traits (Table 1). This suggests that the recommended horticultural practice of enriching conventionally ventilated greenhouses to 1000 μl CO_2/liter (3, 4, 6, 13, 18) probably has no effect on the flavor or acceptability of the tomatoes. This is consistent with the results of Davies and Winsor (7, 17) who found that CO_2 enrichment did not significantly affect reducing sugars and total solids content, but decreased acid slightly. Madsen (11), on the other hand, has found that 1000 μl CO_2/liter increased sugar content 8% and decreased titratable acidity 5%, which should enhance sweetness (12).

A similar comparison between the mean scores for the 1000 and the 1350 μl CO_2/liter-unventilated treatment shows no significant differences in any category except overall consumer acceptability, where the 1350 treatment scored better than the 1000 (Table 1). In general, however, differences in CO_2 concentration in either the unventilated or the ventilated greenhouses had little effect on the panelists' evaluations. Ventilation, on the other hand, had significant effects. The 1000 μl CO_2/liter-ventilated treatment scored significantly better than the 1000 μl CO_2/liter-unventilated treatment in color, flavor, acceptability, and rank, which suggests a disadvantage of unventilated greenhouses. However, the unventilated treatment scores were almost as good as the hydroponic scores and much better than the field scores. Therefore,

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Table 1. Mean sensory panel scores and vitamin contents for tomatoes grown in "ventilated" and "unventilated" greenhouses at various CO_2 enrichments and at standard and 1.5 × standard nutrient concentrations.

Treatment	Quality Trait						Vitamin A (USP units/100g)		Vitamin C (mg/100g)	
	Color	Texture	Aroma	Flavor	Accep.	Rank	N-65	Tropic	N-65	Tropic
Ventilation — CO_2 (μl/liter)										
Vent. — ambient	77a[z]	75a	70a	67a	71a	6.4a	570b	660b	13a	17a
Vent. — 1000	77a	75a	72a	67a	71a	6.3a	690a	650b	15a	15b
Unvent. — 1000	68b	71a	67a	59b	64b	5.4b	770a	740a	14a	15b
Unvent. — 1350	70b	72a	68a	63ab	66a	5.6b	760a	750a	15a	14b
Nutrient concentration										
Standard	69B	72a	68a	61B	65B	5.4B	660a	690a	15a	15a
1.5 × standard	77A	74a	71a	67A	71A	6.4A	730a	710a	14a	15a

[z]Mean separation by LSD after F test (5) at 5% level (lower case) or 1% level (upper case). No interactions were significant.

the quality impairment may not be large enough to preclude the use of unventilated, CO_2-enriched greenhouses that can increase yields by 50% (10).

Nutrient concentration also had significant effects on quality. The high nutrient tomatoes scored significantly better than the standard nutrient tomatoes in color, flavor, acceptability, and rank (Table 1). Improving the flavor and acceptability of tomatoes with higher nutrient concentrations is an interesting possibility, but probably not very practical because the higher concentrations did not increase yields.

Vitamin analyses. The tomatoes for the vitamin analysis were sampled from a fall crop of 'N-65' tomatoes on November 13, 1978, and from a spring crop of 'Tropic' tomatoes on May 1, 1979. Six ripe, uniform tomatoes from each treatment were placed in polyethylene bags and frozen overnight in a freezer. On the next day, all samples were packed with dry ice and shipped to the Western Regional Research Center, Berkeley, California, where they were kept frozen until time for the analyses.

The methods of analyses are described in Freed (9). Briefly, 1 tomato comprised 1 sample. It was divided in 2 parts, one part was made into a 50% alcohol slurry and frozen for subsequent Vitamin C analysis; the other part was lyophilized and analyzed for Vitamin A. The Vitamin A was analyzed as β-carotene by column chromatography purification and spectrophotometrically determining the concentration against a set of standards. β-carotene was converted to Vitamin A by the factor of 0.60 mg of β-carotene equals 1 U.S.P. unit of Vitamin A as assigned by the United States Pharmacopeia (15). The total Vitamin C analysis consisted of converting ascorbic acid to dehydroascorbic acid with bromine and determining the dehydroascorbic acid colorimetrically by coupling with dinitrophenylhydrazine.

The Vitamin A concentrations (Table 1) were about 20% lower than the 900 USP units/100 g listed as typical of ripe, raw tomatoes in Agriculture Handbook 8 (16). The Vitamin C concentrations were about 40% lower than the 23 mg/100 g Agriculture Handbook 8 value and 20% lower than an 18.2 mg/100 g mean of a sample of fresh tomatoes that were never frozen. Therefore, it is possible that some deterioration of Vitamins A and C occurred during the freezing and storage before analysis. We assume that if any such decrease in vitamin content occurred, it affected all the treatments equally.

The Vitamin A means for the ambient-ventilated treatment were significantly lower than either of the unventilated treatments for both crops (Table 1). The means for the 1000 μl CO_2/liter-ventilated treatment were intermediate, but were not significantly different from the unventilated treatments for the fall 'N-65' tomatoes and not significantly different than the ambient-ventilated treatment for the spring 'Tropic' crop. There were no significant differences between the 1000 and 1350 μl CO_2/liter-unventilated treatments nor between the standard and high nutrient concentrations.

The Vitamin C data showed no consistent differences. The ambient-ventilated means for the spring 'Tropic' crop was significantly higher than the other treatments, but no other differences were significant. This result is in conflict with the data of Madsen (11) and Barbale (2), who found the ascorbic acid content of tomato fruits grown in 1000 μl CO/liter was 7% higher than those grown in 300 μl CO_2/liter. Considering that no consistent differences were found here and that Madsen found increases in ascorbic acid with CO_2 enrichment, there is no evidence that use of CO-enriched, unventilated greenhouses would be detrimental to the nutritional value of tomatoes.

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